TRANSIT ROUTE SERVICE AREA ANALYSIS USING GIS

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Abstract: It is common knowledge that part of the route location analysis problem requires an accurate estimation of population who would be using this system. Using GIS tools, various approaches are applied for estimating the population on some of the fixed routes in Adelaide, Australia, within the service area of a transit route and the results are discussed in this paper. The outcome of the research shows that when the route lengths are small, the population estimation in the service areas does not differ significantly whichever method used. However, as the route length increases the traditional area ratio method overestimates the population while the network ratio method underestimates the population. Further analysis at census district (CD) level showed consistently good results for the land use method and its estimates were the closest to digital cadastral data method. This research also showed that route buffers tend to overestimate the population significantly compared to the bus stop buffers for routes of longer lengths.

Key Words: transit service planning, GIS, population coverage, route buffer and stop buffer

1. INTRODUCTION

The spatial layout of routes is one of the main sources of complexity that preclude finding an optimal solution for transit network design. Network design should satisfy important criteria such as route coverage, route application, route length and directness of route.

Bus route evaluation standards are evolutionary and the more we deal in their use, the better we understand their individual application. Bus transit service planning in most urban areas is mainly an outgrowth of historic and geographic circumstances. The objective is to provide the best possible service to the greatest number of people within the governing economic constraints.

Transit routes are located to provide convenient linkages between an origin and destination in such a way that out of vehicle time, such as access and transfer time is minimised. The design of public transportation networks is made difficult by a multitude of conflicting objectives. For example, networks designed to minimise travel time cannot be expected to maximise coverage and accessibility.

The planning of transit routes requires an understanding of demographics, land use and travel patterns. Geographic Information Systems (GIS) offer tools that assist with the effective planning of transit routes. The advantages of using GIS tools in transit planning compared to more traditional planning include the overlay and visualization of complex data. These data can be combined and analysed in new ways using GIS compared with more traditional database methods

It is common knowledge that route location analysis requires an accurate estimation of the population using the transit system. The gross patronage potential of a route is based on the population residing within the service catchment area. Population is the best representation of potential usage, in terms of daily trips, at the point of origin. Given that the fundamental purpose of a bus is to carry passengers, in volume, population is a good indicator of the number of people living in proximity of a transit service as stated by Howard P.Benn in TCRP (1996), " run the bus where the people are"

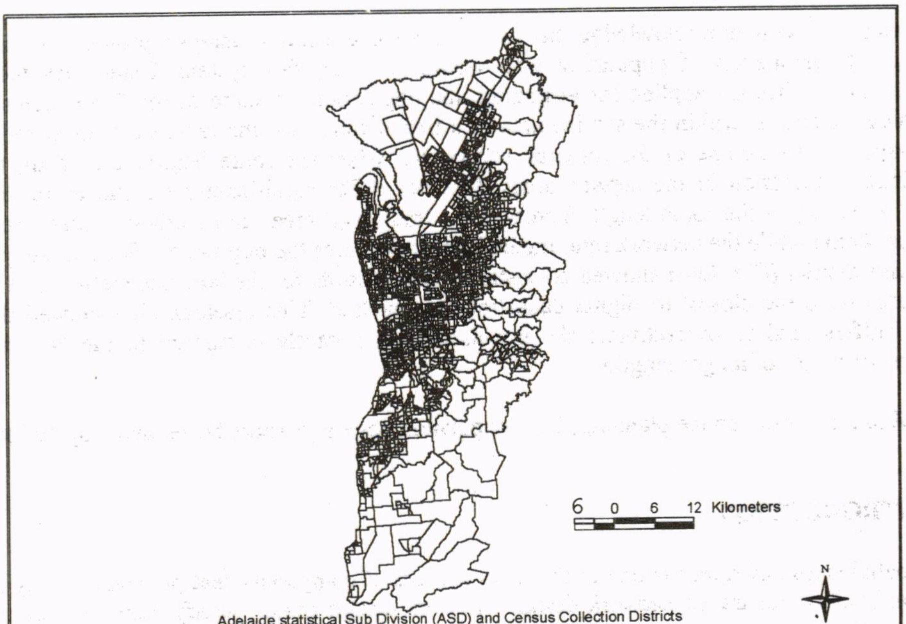

Figure 1- The Study area

Transit Cooperative Research Program (TCRP) in their publication (1995) titled "Bus route Evaluation standards" states that 74 percent of respondents of transit agency survey, use population density as a criterion in route design. Hence, realizing its importance, population estimation methods are tested using data for Adelaide Statistical Division (Figure 1) and those methods include (a) area ratio method (b) network ratio method (c) land use ratio method and (d) digital cadastral data base method.

2. SERVICE AREA

Whether or not a transit service is provided near one's origin and destination is a key factor in the choice to use the transit service. The concept of area coverage expresses how many people live within a reasonable walking distance of a transit route. The area within a 5 minute walk (Bus route and schedule planning guidelines, NCHRP report #69,1980) from a bus stop is traditionally considered the primary service area. The standard definition of service area is the region within 0.25-mile (0.4 kilometer) of a route or stop in a transit service. However, any such service area is arbitrary in that some of those who live outside the service area still use the transit service and others refuse to walk even a short distance to a route/stop. Nonetheless, the service-area concept persists as one of the most useful and used tools for transit planning.

3. APPROACHES AND ASSUMPTIONS

O'Nell *et al*, (1992) applied area ratio and network ratio methods on three neighborhoods in Logan, Utah. The Euclidean buffer line (route buffer), parallel to the transit route is drawn at approximately 1600 ft (487 meters). In their research, the network ratio method had shown to be more accurate for determining the number of households in primarily residential, modified grid street network areas. However in the current research, apart from these approaches the land use ratio and digital cadastral database approaches are discussed and the results compared.

There are a number of assumptions underlying the four methods, which can impact upon the estimate of population. The area ratio method is based on the Australian Bureau of Statistics (ABS) population census using the census collection district (CCD) as a real unit. The CCD is primarily designed by the ABS as the workload for one collector, but does take account of property boundaries and natural features, and is usually 300-400 households. The number of households does differ between CCDs but in urban areas the CCDs are far more uniform in size (area) and households than fringe or rural CCDs which are often large in area in an attempt to capture 300-400 households. In the context of this research, when estimating the population, it is assumed that the population is uniformly distributed throughout the CCD, but in reality if a portion of the CCD is inaccessible to the transit route due to natural or manmade barriers, this method will not detect such things and thereby may produces errors in estimation.

The network ratio method uses the ratio of the length of the street network within the buffer area to the total street network length in the CCD to estimate the population. This assumes that the number of houses on a street is proportional to the street length. Clearly, this assumption is questionable; especially where land use is predominantly commercial, industrial or recreational.

The land use method is an attempt to overcome these shortcomings by calculating the extent of residential land use in the buffer area as a proportion to the total residential land use in the CCDs in the service area.

The fourth method is the most accurate and uses digital cadstral data (DCDB) and calculates the dwellings at the single parcel level within the buffer in relation to the total dwellings within CCDs in the service area. People live in dwellings and a measure of the number of dwellings should provide a more accurate estimate of the population than the other three methods outlined above. Bell *et al*, in their forth coming paper have shown that the dwelling count obtained by DCDB method in 77% of CDs has tallied with ABS count accurately (i.e. less than 5% error) and in the remaining CDs also the percentage of error is very small (i.e. less than 10% error). Hence the other methods results are compared taking DCDB method as benchmark.

4. DATA BASE

The study area comprises the Adelaide Statistical Division (ASD). Adelaide is the capital city of the state of South Australia (SA) in Australia. The database for this study was developed from the following resources.

(i) 1996 Census data
(ii) Transit route information from the SA Passenger Transport Board
(iii) Digital cadastral data base for the city
(iv) Land use data for the city
(v) Street network for the city

5. COMPUTATIONAL EFFORT

The analysis for this research has been carried using Environmental System Research Institute's (ESRI's) 'Arc-View' software and hence the data used is in "shapefile"(.shp) format. The Census data from 1996 Australian Census of Population and Digital statistical boundaries (to facilitate the analysis and display of census data) are extracted from CData96. Cdata96 is a CD-ROM product that combines data from the 1996 census of population and Housing with digital maps, using MapInfo Professional, a spatial information management systems.

The data compilation process involved collection of data form various organizations which may not follow the same projection system and also the same GIS software. Hence the data collected is converted into single projection system ("Australian Map Grid" {AGD66}) shape files by using the Universal Translator utility in MapInfo Professional software.

6. AREA RATIO METHOD (ARM)

In this method for each bus stop of the selected route, 400 meter (acceptable walking distance to catch a bus) buffers are created (Figure 2) with the objective of estimating the total population of all buffer polygons in this route.

In most of the cases a polygon generated from the buffer intersects the census district polygon partially. Since the population of census district polygons are known, we can estimate the population in the buffer polygons using (area ratios) the following equation:

$p_i = (a_i / a_z)^* \; p_z$ ....(1)

Where

p_i = Population in service polygon i within walking distance of transit stop
a_i = Area of service polygon
a_z = Area of analysis census district polygon z
p_z = Population of analysis census district polygon z. (census data)

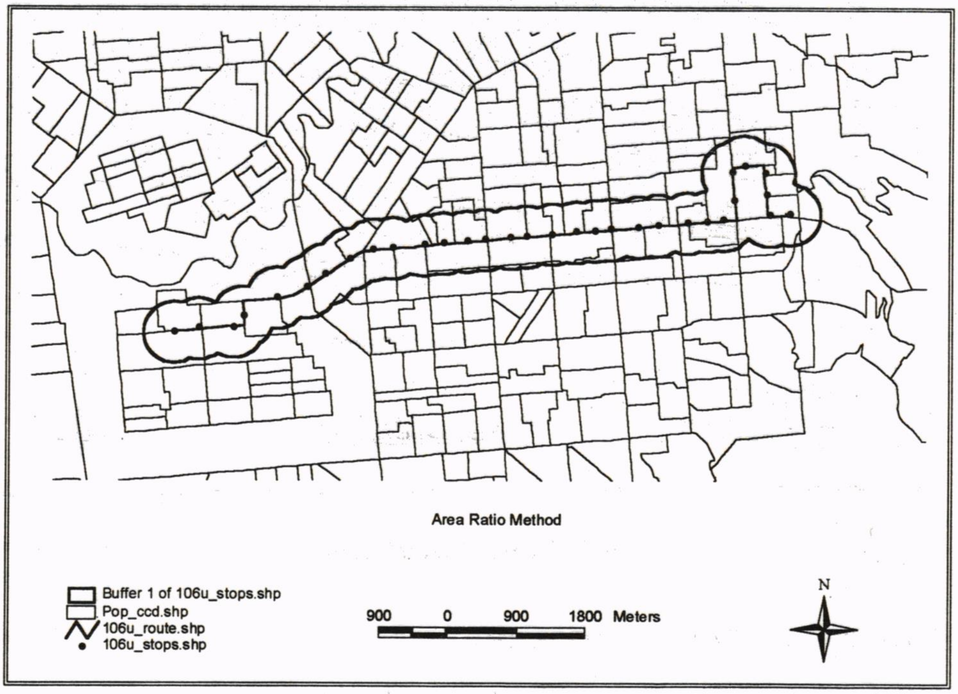

Figure 2 Area Ratio Method

7. NETWORK RATIO METHOD (NRM)

In this method instead of taking the ratio of the areas, the ratio of the street lengths (Figure 3) of all streets within the buffer to the street lengths within the census districts in the service area is calculated and then the population in the service area is estimated using the following equation:

$P_i = (n_i / n_z)^* \; p_z$ ....(2)

where

p_i = Total Population with in the service area
n_i = Sum of street kilometers within the service area

n_z = Sum of street kilometers with in the collection districts intersected by the route
p_z = Total population in the collection districts intersected by the route

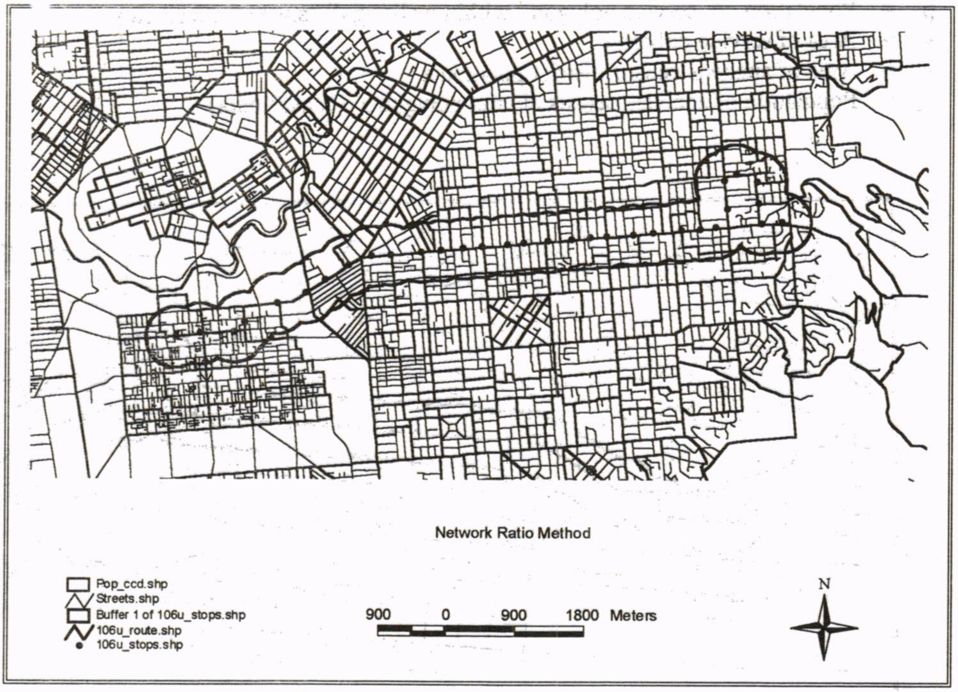

Figure 3 - Network Ratio Method

8. LAND USE RATIO METHOD (LRM)

In this method, the ratio of the residential area in the buffer polygon (Figure 4) to the total residential area in the census district polygons in the service area is calculated and then population is estimated using the following formula

$p_i = (r_i / r_z)^* \ p_z$ ....(3)

Where

p_i = Population in service polygon i with in walking distance of transit stop
r_i = Residential land use area in the service polygon
a_z = Residential area of analysis census district polygon z and
p_z = Population of analysis census district polygon z.

Figure – 4 Land use Ratio Method

9. DIGITAL CADASTRAL DATA BASE METHOD (DCDB METHOD)

The most accurate method is to use digital cadastral data. This requires data to be joined from the valuation database and the dwelling count calculated. The geographic analysis and research unit within Planning SA (Department for Transport, Planning and the Arts) calculates dwelling numbers annually. For this method, dwellings within the buffer area (Figure 5) are divided by the total dwelling count for the CCD using the following equation.

$$p_i = (d_i / d_z)^* \; p_z \quad \text{.......................................} (4)$$

Where

p_i = Population in service polygon i with in walking distance of transit stop
d_i = Number of dwelling units within the service polygon
d_z = Number of dwelling units with in the analysis census district polygon z and
p_z = Population of analysis census district polygon z.

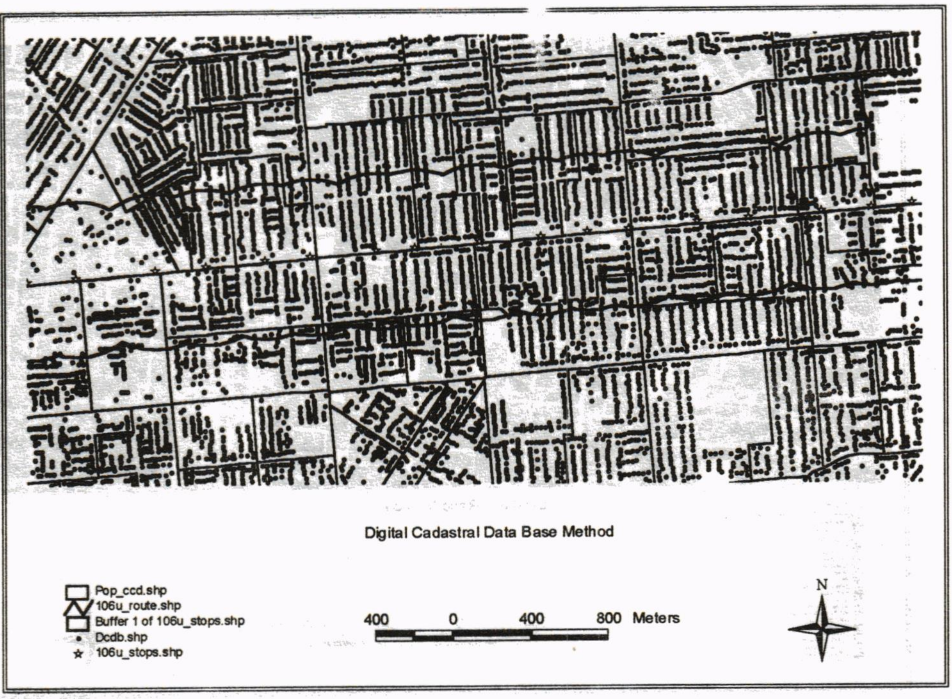

Figure -5 DCDB Method

10. ANALYSIS

The four methods detailed above have been applied to four bus routes for the city of Adelaide, South Australia. These routes, of varying lengths, are selected as they represent four directions (one route for each direction- refer Figure 6). All routes are radial and originate in the CBD

In the study of Logan, Utah, O'Nell *et al*, (1992) concluded that the network ratio method provided better results than the area ratio method. This is contrary to the findings in this study, where network ratio method did not yield good results. This may be due the fact that all routes are connected to the CBD are proximate to the city center where the network distances have no direct relation with resident population due to high commercial activities.

The figure 7 shows that there is no significant difference in the outcome of the methods used for shorter routes, but, as the route lengths increase the area ratio method tends to overestimate the population compared with the DCDB method. The network method tends to underestimate the population.

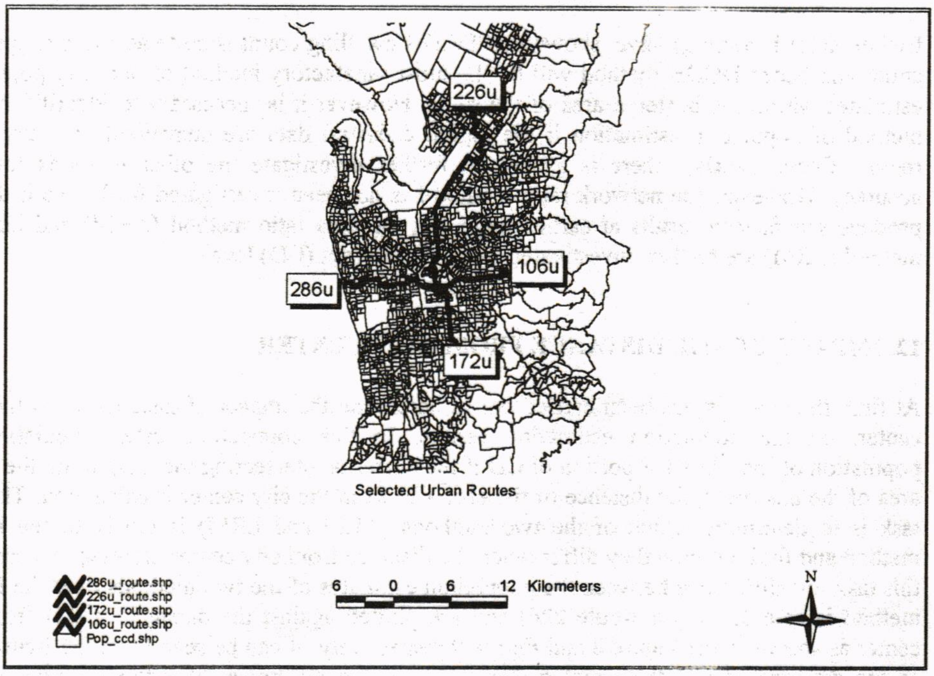

Figure – 6 Selected urban routes

Population coverage by various methods

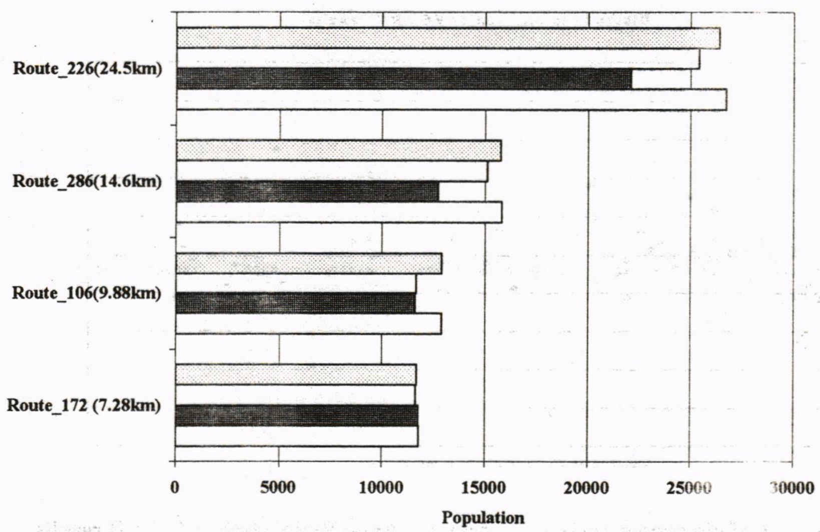

Figure 7 -Population coverage by various methods

11. NEED FOR FURTHER INVESTIGATION

Bell *et al*(forth coming) have shown that DCDB dwelling count is quite accurate to the ABS count and hence DCDB method will be the most satisfactory method of deriving population estimates within the buffered area of the route. However it is necessary to identify the best method of population estimation if the digital cadastral data are unavailable for any given region. Consequently, there is a need to further investigate the other methods for their accuracy. However, the network ratio method has not been investigated further as it did not produce satisfactory results at earlier stage. So, the area ratio method (ARM) and land use method (LRM) are further investigated at census district (CD) level.

12. IMPACT OF THE DISTANCE FROM CITY CENTER

At first, the analysis has been carried out to determine the impact of distance from the city center, on the population estimation results. In this connection, after calculating the population of the CD's (or portion of CD if the buffer is intersecting the CD) along the buffer area of the bus route, the distance of the each CD from the city center is calculated. The next task is to determine which of the two methods (ARM and LRM) is closer to the DCDB method and find out how they differ when the distance from city center increase. To carry out this task, the difference between the population estimates of the two methods over the DCDB method is calculated (for Route 226) and are plotted against the distance of CD from city center as shown in the Figure 8 and Figure 9 respectively. It can be seen from the figures that as the distance of CD from city center increase, the difference of estimates over DCDB method differs significantly for the area ratio method (ARM). This can be further confirmed from the descriptive statistics results shown in the Table 1 The table shows that as the distance from city center increase the land use ratio method maintained its errors more consistently where- as the error in the area ratio method varied significantly. Similar trend has been observed for all the routes discussed earlier.

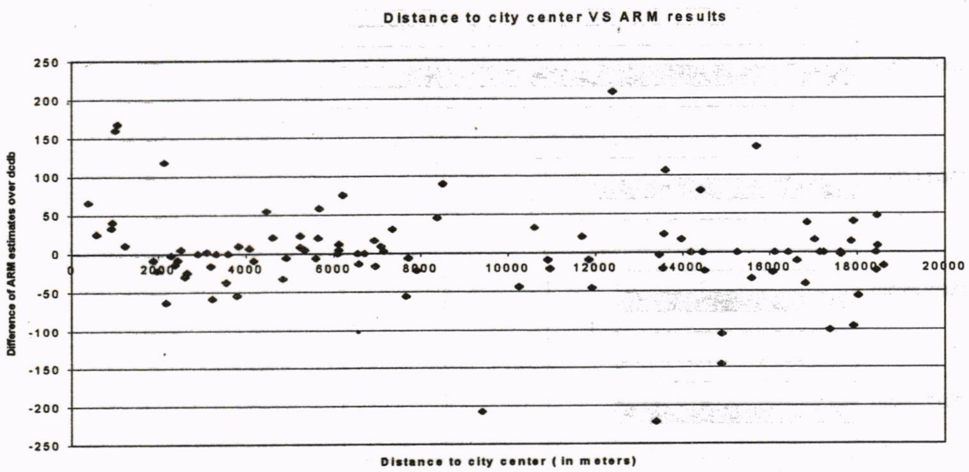

Figure 8 Impact of distance from the city center – Area Ratio Method (ARM) results

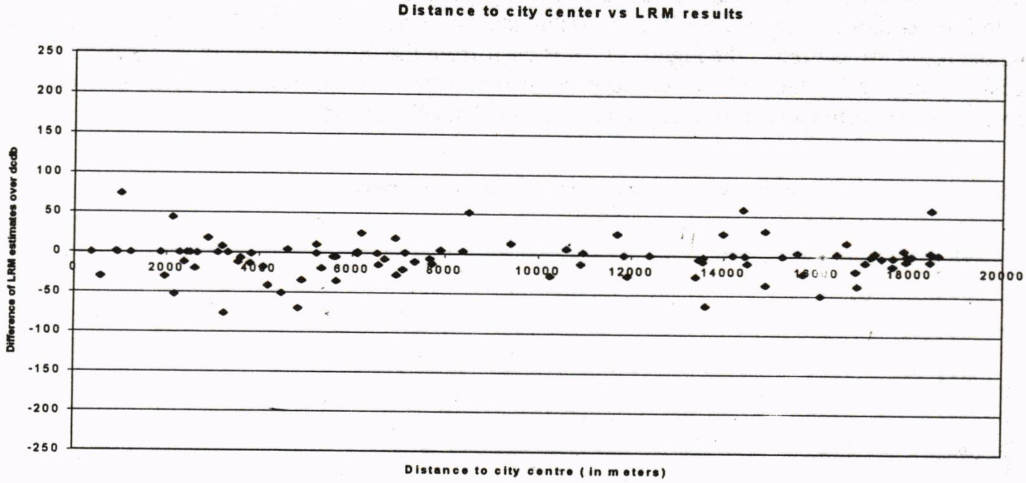

Figure 9 Impact of distance from the city center – Land Use Ratio Method (LRM) results

Table 1 Descriptive statistics with respect to the distance from city center

Method	Difference of the two methods with dcdb method - **for CDs which are < 5kms from city center**								
	N	Minimum	Maximum	Mean	Std.	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std.Error	Statistic	Std.Error
ARM	33	-63.30	168.30	13.20	55.93	1.415	0.409	1.905	0.798
LRM	32	-76.53	73.56	-10.44	29.21	0.134	0.414	1.980	0.809
Method	Difference of the two methods with dcdb method - **for CDs which are 5 - 10 kms from city center**								
	N	Minimum	Maximum	Mean	Std.	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std.Error	Statistic	Std.Error
ARM	24	-207.36	89.52	2.89	54.66	-2.382	0.472	9.629	0.918
LRM	24	-35.17	52.46	-1.48	17.98	0.957	0.472	2.630	0.918
Method	Difference of the two methods with dcdb method - **for CDs which are 10-15kms from city center**								
	N	Minimum	Maximum	Mean	Std.	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std.Error	Statistic	Std.Error
ARM	17	-221.40	209.07	-8.34	95.81	-0.600	0.550	1.733	1.063
LRM	17	-63.80	58.69	-1.92	28.4	-0.004	0.550	0.973	1.063
Method	Difference of the two methods with dcdb method - **for CDs which are 15-20kms from city center**								
	N	Minimum	Maximum	Mean	Std.	Skewness		Kurtosis	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std.Error	Statistic	Std.Error
ARM	44	-221.40	209.07	-2.13	71.50	-0.712	0.357	3.894	0.702
LRM	44	-63.80	58.69	-2.29	22.19	0.295	0.357	1.758	0.702

13. IMPACT OF THE RESIDENTIAL DENSITY

The objective in this exercise is to study how far the two methods (i.e. area ratio method and land use method) compare with the DCDB method at varying levels of residential density.

The area of the residential land use is calculated in each CD (or portion of CD if the buffer is intersecting the CD) falling within the stop buffer of the route. The ratio of this area to the total area of the CD is calculated. For each CD, the population is estimated using the all the three methods as discussed earlier. The percentage of difference over the DCDB method is estimated for the area ratio method and is plotted against the residential land use ratio (for the route 226) as shown in the Figure 10 and similar analysis is done for the land use ratio method and the result are plotted in the Figure 11. It is clear from the figures that at lower residential densities, area ratio method is not very consistent where-as the land use ratio method produces closer estimates to the one produced by the DCDB method.

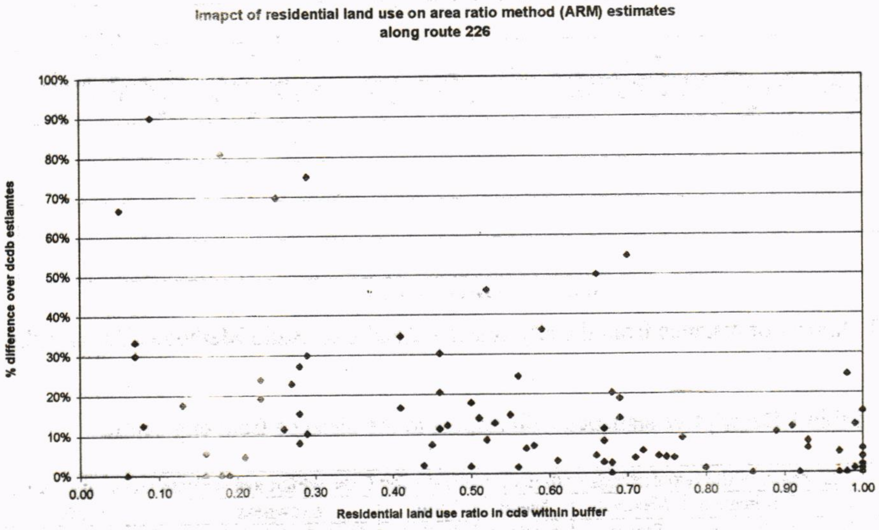

Figure 10 Impact of land use (residential) ratio on ARM estimates for Route 226

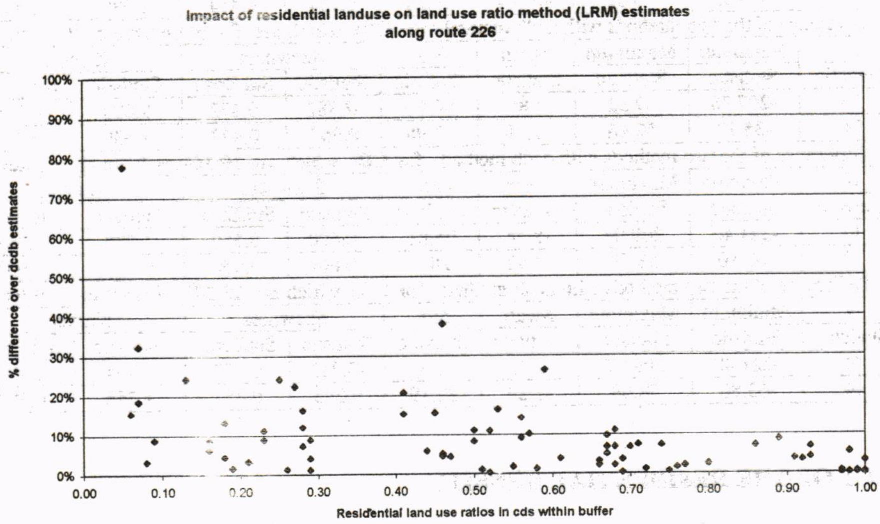

Figure 11 Impact of land use (residential) ratio on LRM estimates for Route 226

14. IMPACT OF CENSUS DISTRICT (CD) SIZE

In this exercise, the size of the CD within the buffer and its impact on the results of the two methods are discussed. In Figure 12, the ratio of the CD in the buffer to the total CD area is plotted on X-axis. In the Y-axis, the percentage of difference of estimates of area ratio method over DCDB method are plotted for Route 286. Similarly in Figure 13, the Y-axis shows corresponding results of land use ratio method. From the analysis, it is revealed that there is no strong linear relationship (R^2 for area ratio method was about 0.32 and for land use ratio method is around 0.41) between the area ratio of CD with in the buffer to the accuracy of population estimation. However, in the case of land use ratio method the trend is more consistent and the standard error is significantly less. Similar results are observed for the other routes considered.

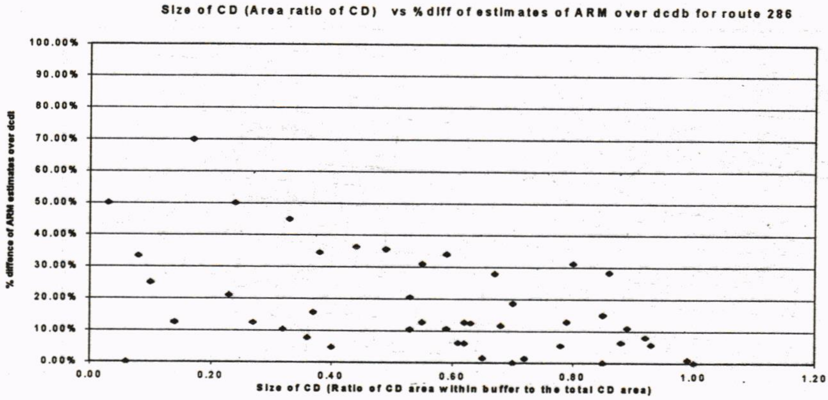

Figure12 Impact of the size of CD – Area Ratio Method

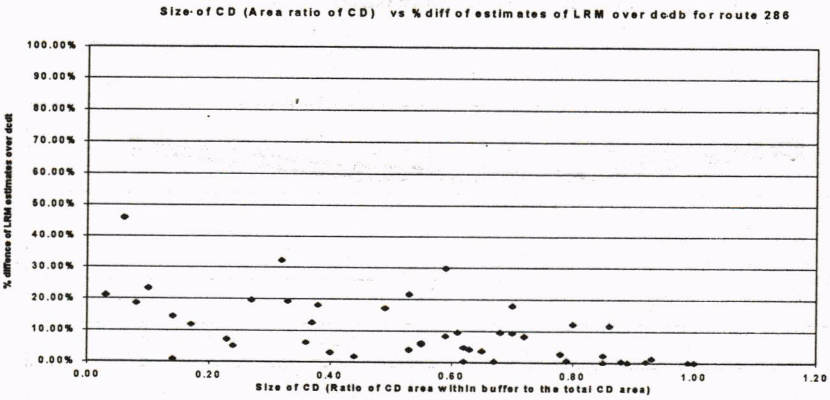

Figure 13 Impact of size of CD – Land Use Ratio method

15. BUS ROUTE BUFFER VS STOP BUFFER

It is not always possible to get bus stop location details and therefore, for comparison purposes, these methods are applied to calculate how the estimates differs using route buffers (Figure 14) instead of bus stop buffers. The 400-meter buffer is applied along two routes and the population estimated. From Figure 15, it is clear that the population figures tend to be overestimated using route buffers. In particular, the population overestimation increases as the length of the route increases since the bus stop spacing increases when the population density decreases.

For the Adelaide data, the stop buffering provides a more reliable estimate of the population who are potential transit service customers than the buffering the transit route. On this basis, further research should be based upon bus stop buffers when possible and only use route buffering in the absence of stop data.

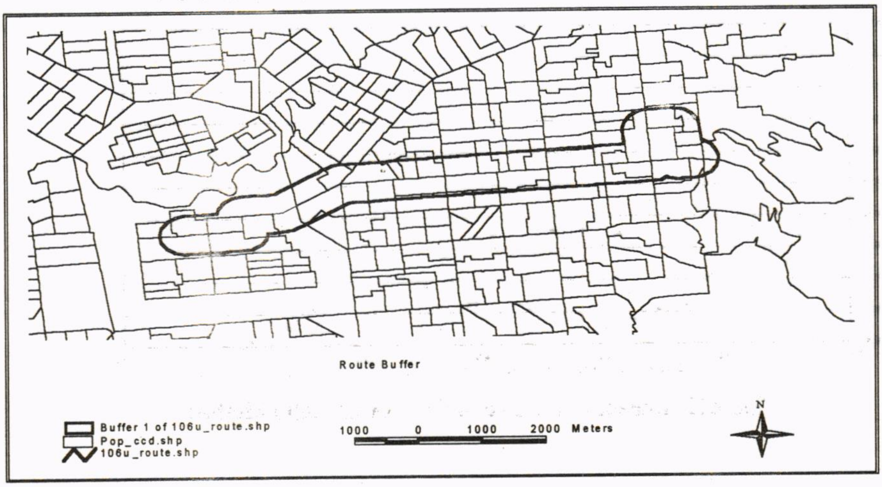

Figure 14 - Bus route buffer

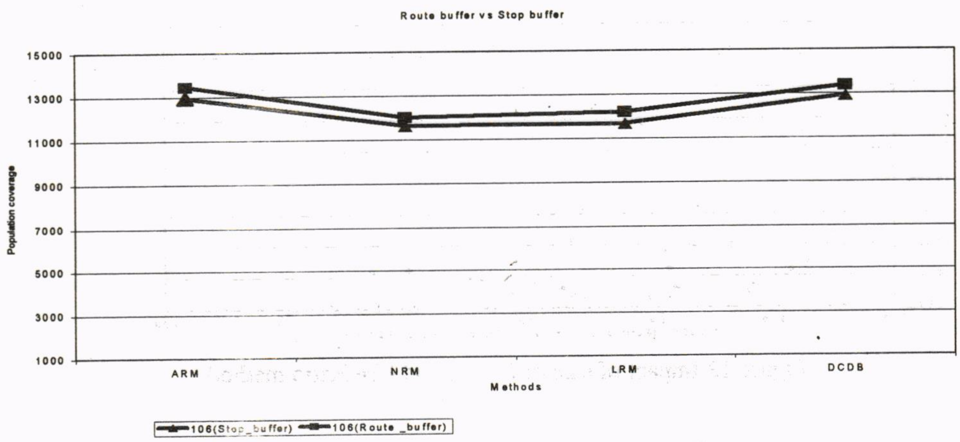

Figure 15 - Stop buffer Vs Route buffer

16. CONCLUSION

This paper has presented a GIS based approach to population estimation within transit service areas based on both buffering transit stops and routes. When the transit route lengths are small, the population estimation in the service areas does not differ significantly whichever method is applied. However, as route length increases the traditional area ratio method overestimates the population while the network ratio method underestimates the population. Further analysis at census district (CD) level showed consistently good results for the land use method. This research also showed that route buffers tend to overestimate the population significantly compared to bus stop buffers for routes of longer lengths. Consequently, in order to achieve better population estimation for transit service areas it is suggested that the best method is a combination of transit route stop buffers and the digital cadastral data. However, if the cadastral database is unavailable, the best alternative is to use the land use data.

ACKNOWLEDGMENTS

The authors would like to acknowledge the valued contributions from the Director of the Transport Systems Centre, Professor Michael Taylor of University of South Australia and all the members of transport center for their support for this research. They would also like to thank the staff members of Passenger Transport Board of South Australia and Transport SA, Planning SA and Key center for social applications of GIS (GISCA) for their cooperation in connection with the data collection.

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